AQUAPONIC BIOFILTER SYSTEM USING *HELICONIA* SP. FOR AMMONIA REMOVAL IN LAKE

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SPECIALLY DEDICATED TO MY ADORED PARENTS, MY WIFE, FAMILY AND FRIEND FOR ALWAYS BEING BESIDE ME. THANKS FOR ALL THE PATIENCE, SUPPORT AND LOVE.

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ABSTRACT

Lakes are considered as one of the natural water resources in Malaysia. The quick pace of development around many lakes catchment areas has a significant impact on water quality. Consequently, biofilter aquaponic system for ammoniacal nitrogen removal in lake near non-point sources such as oil palm plantation, factory and educational building were studied. Aquaponic is a system that mutually integrates aquaculture and plant cultivation. Aquaponic biofilter system also applies phytoremediation mechanism to reduce nutrient. Therefore, phytoremediation of lake water in *Tasik Teknologi* in campus area of Universiti Tun Hussein Onn Malaysia (UTHM) was performed in 7 days by using *Heliconia* sp. as phytoremediate plant. This study was conducted in a greenhouse experiment to control the environments conditions (with different temperature and photoperiod), which consists of five hydroponic tanks, and one fish culture tank with the 40 watt of water pump was run circulation of water. A physicochemical characteristic of *Tasik Teknologi* was compared to Interim National Water Quality Standard Malaysia (NWQSM) after phytoremediation. *Heliconia* sp. after phytoremediation was undergoes analysis for plant nutrients by using Ion Chromatography (IC) in three major parts; leaves, roots and stem. The result shows that *Tasik Teknologi* has mean values of AN (3.95 mg/L), NO_2 (0.12 mg/L), NO_3 (1.36 mg/L), BOD (105.70 mg/L), COD (10.30 mg/L), TSS (19.70 mg/L), Turbidity (12.30 mg/L), temperature (28.80^oC), DO (9.40 mg/L) and pH (6.51), respectively. Phytoremediation has reduced AN and NO_3 from the lake water sample by *Heliconia* sp. with 66.00% and 92.03% removal efficiency, respectively. Besides that, the concentration of DO during phytoremediation was increased 47.82 % from 2.4 mg/L to 4.6 mg/L. Furthermore, the uptake of AN in three major parts of *Heliconia* sp. leaves, stem and root were found to be 4.40 %, 1.12% and 4.20%, respectively. The *Heliconia* sp. has the ability in reducing AN and NO_3 in lake water with efficiently and practically.

ABSTRAK

Tasik merupakan sumber semulajadi dan air yang penting di Malaysia. Kadar yang cepat untuk pembangunan di seluruh kawasan tadahan tasik mempunyai kesan yang ketara terhadap kualiti air. Oleh itu, sistem penapis-bio akuaponik untuk penyingkiran ammoniakal nitrogen di tasik berhampiran bukan titik punca seperti ladang kelapa sawit, kilang dan bangunan pendidikan telah dikaji. Akuaponik adalah satu sistem yang saling mengintegrasikan akuakultur dan penanaman tumbuhan. Akuaponik penapis-bio sistem juga menggunakan mekanisme fitopemulihan untuk mengurangkan nutrien. Oleh itu, fitopemulihan air tasik di Tasik Teknologi di kawasan Kampus Universiti Tun Hussein Onn Malaysia (UTHM) telah dijalankan selama 7 hari dengan menggunakan pokok *Heliconia* sp. sebagai pokok fitopemulih. Kajian ini dijalankan dalam satu eksperimen rumah hijau untuk mengawal keadaan persekitaran (dengan pelbagai bacaan suhu dan foto masa), yang terdiri daripada lima tangki hidroponik, dan satu tangki ikan dengan 40 watt pam air untuk menjalankan peredaran air. Ciri fizikokimia Tasik Teknologi telah dibandingkan dengan Piawaian Kualiti Air Negara Malaysia (NWQSM) selepas proses fitopemulihan. *Heliconia* sp. selepas proses fitopemulihan terus di analisis nutrien tumbuhan dengan menggunakan ion kromatografi (IC) dalam tiga bahagian utama; daun, akar dan batang. Hasilnya menunjukkan bahawa Tasik Teknologi mempunyai nilai AN (3.95 mg/L), NO_2 (0.12 mg/L), NO_3 (1.36 mg/L), BOD (105.70 mg/L), COD (10.30 mg/L), TSS (19.70 mg/L), kekeruhan (12.30 mg/L), suhu (28.80 ^oC), DO (9.40 mg/L) dan pH (6.51). Fitopemulihan telah mengurangkan AN dan NO_3 dari sampel air Tasik oleh *Heliconia* sp. sebanyak 66.00% dan 92.03% dengan kecekapan penyingkiran. Di samping itu, larutan DO semasa fitopemulihan meningkat sebanyak 47.82% daripada 2.4 mg/L kepada 4.6 mg/L. Tambahan pula, penyerapan AN dalam tiga bahagian utama *Heliconia* sp. iaitu daun, batang dan akar adalah 4.40%, 1.12% dan 4.20%. *Heliconia* sp. mempunyai keupayaan untuk mengurangkan AN dan NO_3 dalam air tasik dengan cekap dan praktikal.

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LIST OF SYMBOLS AND ABBREVIATIONS

^{o}C	Degree Celcius
ANOVA	Analysis of Variance
ABS	Aquaponic Biofilter System
AOB	Ammonia oxidizing bacteria
BOD	Biochemical Oxygen Demand
cm	Centimeter
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
EPA	Environmental Protection Agency
FAO	Food Agriculture Organization
HRT	Hydraulic Retention Time
HLR	Hydraulic Loading Rate
INWQS	Interim National Water Quality Standards
mg/L	Miligram per liter
MPOB	Malaysia Palm Oil Board
N	Nitrogen
AN	Ammoniacal Nitrogen
NH_3	Ammonia
NO_3^-	Nitrate
NO_2^-	Nitrite
NOB	Nitrite oxidizing bacteria
P	Phosphorus
POME	palm oil mill effluent
TN	Total nitrogen
TSS	Total suspended solid

UTHM	Universiti Tun Hussein Onn Malaysia
WQI	Water Quality Index

CHAPTER 1

INTRODUCTION

1.1 Background of study

Malaysia is one of the countries that are bestowed with biodiversity from all sources including rivers, lakes and sea. Rivers and lakes are natural heritages that should be preserved at all cost. The history of human civilization has proven the importance of rivers and lakes to humans but development activities have affected the quality status of these waterbodies. Pollution causes the waterbodies to lose its benefits to human and other living things. The pollution comes from point source (factories and sewage treatment plant) and non-point source (oil, fertilizers and lawn chemicals). This study focuses on palm oil plantation as non-point source and was conducted to evaluate the water quality changes in the lake of *Tasik Teknologi* at Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia. Hence, the background study of palm oil plantation widely well known in Malaysia since a few years ago.

Palm oil plantations make up approximately 77% of agricultural land in Malaysia (Nadzir *et al.*, 2019). Palm oil plantation is broadly established in tropical countries such as Malaysia, Indonesia, and Thailand for its commercial oil. The Malaysia Palm Oil Board (MPOB) stated that the palm oil plantation area in Malaysia reached 5.85 million

hectares in 2018, an increase of 0.7% from 5.81 million hectares in 2017 (MPOB, 2018). Sarawak is the largest state with palm oil planted area in Malaysia. It has 1.57 million hectares or 26.9% of the total palm oil planted area, followed by Sabah with 1.55 million hectares or 26.5%. In comparison, Peninsular Malaysia (with 11 states) is accounted for 2.73 million hectares or 46.6% of the total planted area. Johor is the second largest state with the palm oil plantation area of 747,562 hectares and an estimated 12.8% in peninsular Malaysia (MPOB, 2018). Therefore, the increasing in total plantation area affects the utilization of fertilizer. Fertilizer was used to increase the production of palm oil in Malaysia.

The plantation may pose significant environmental pollution from palm oil mill effluent (POME), fertilizers, pesticides, insecticides and herbicides (Abdullah & Sulaiman, 2013). The excessive utilization of fertilizers in palm oil plantation that runoff to the nearby water body can cause eutrophication due to the high loads of nitrogen (N) and phosphorus (P) (Al-Badaii, Shuhaimi & Gasim, 2013). The authors reported the concentration of N and P in river water contaminated from agricultural activities at 1.91 mg/L and 1.9 mg/L, respectively. POME has high nutrient concentrations and pollutants, so releasing it into a water body will lead to algal blooms and subsequent loss of biologically active oxygen in the water (Isabelle, 2017). The lack of oxygen will eventually cause a loss to all life in the aquatic ecosystems. In Madaki & Seng (2013), the N and P concentrations in lake water influenced by POME wastes were reported 750 mg/L and 180 mg/L, respectively. Both researchers found that the level of N and P were exceeded the level regulated by Interim National Water Quality Standard for Malaysia (NWQS) which are <0.1 mg/L and 0.2 mg/L, respectively. Nadzi *et al.* (2019) stated that the application of toxic agrochemicals such as phosphate fertilizer can contaminate the nearby surface water with some heavy metals, organic and inorganic matters. Thus, it will negatively impact aquatic species as well as drinking water sources. Aquaponic Biofilter System (ABS) is one of the potential treatment systems that can be applied to treat aquaculture wastewater. ABS use the combination of aquaculture and hydroponic systems, where (*Heliconia* plants) are planted in a recirculating system that utilizes less water than the traditional farming. Nutrients contained in fish tanks are recycled into plant biomass in the presence of nitrifying bacteria that will convert the excreted

ammoniacal nitrogen (AN) to nitrite and then to nitrate. The water in recirculating system will be clear from ammonia and others substances by using application of plants that potentially as green technology compare others conventional method. There are few researcher that interested in this system and the results from their studies were satisfactory. Lam *et al.* (2015) claimed that ABS was used to treat aquaculture pond. Endut *et al.* (2009) also used ABS to treat nutrient-–rich wastewater by using water spinach. Lam *et al.* (2015) and Endut *et al.* (2009) revealed that 70% and 86 % of ammoniacal nitrogen (AN) had been removed, respectively, confirming the ability of ABS to reduce nutrient from wastewater. Estim *et al.* (2018) reported a removal of 59% of PO_4-N and 50% of AN from aquaculture wastewater by an indoor aquaponic system. The satisfactory results of Estim *et al.* (2018) study could be due to the lack of photoperiod for photosynthesis process. However, previous studies have not investigated the detail on the optimisation study for the efficiency of ABS. Factors such as photoperiod and temperature of ABS in laboratory scale are found to be important which can determine the survival of the plant over a certain time. These two factors are identified to influence the growth of plant, the time to flower, and the performances on efficiency removal of nutrients. Ha *et al.* (2013) stated that photoperiod and temperature have been reported to affect floral initiation and flower development of flowering plant families.

There are many advantages of aquaponics such as reducing the need for formulated fertilizers, eliminating the possibility of agricultural run-off, and cleansing of water through biofilter treatments (Turcios & Papenbrock, 2014). Turkmen and Guner (2010) stated that there is no mixing fertilizer involved in aquaponic, making it a great way for beginners to cultivate plants. Nutrients excess in the lake can be treated with filtration method using plants. Plants act as biofilter to pollutant in water by the uptake of N and P from water for growth, thus improve the water quality. The nutrients released from fish excreta and microbial breakdown of organic wastes are used by plants in aquaponic systems (Yavuzcan *et al.*, 2017). In the system, the plant component serves as a biofilter; therefore, a separate biofilter is not needed unlike aquaculture systems. In addition, the biofilter can generates income through the sale of the economic plant products (Saha *et al.*, 2016). Hence, the aquaponic systems develop an economically advantageous symbiotic system, where aquatic organisms and the plant component benefit each other

and while the grower receives two valuable commercial products. In contrast, the crop plant is the only marketable product in aquaponics and it is devoid of the commercial aquatic species and associated nutrient supply.

Many plant species such as *Heliconia sp.* ornamental plants (*Heliconia psittacorum*) have been investigated for removal of nitrogen (ammoniacal nitrogen) in phytoremediation. Konnerup *et al.* (2009) claimed that *Heliconia* sp. removed 13% of total nitrogen from domestic wastewater containing 27 mg/L nitrogen. Mendoza *et al.* (2015) reported that *Heliconia* sp. removed 39% of total nitrogen from domestic wastewater. These two findings showed the low efficiency of *Heliconia* sp.to remove TN in domestic wastewater. The low ability of *Heliconia* sp.as biofilter in this system implies that sub-–surface flow systems have limited use if nutrient removal is required. Plant uptake is a significant removal process for nutrients, and only in lightly loaded system can this be sufficient to secure low effluent concentrations. Conversely, Parra (2016) found that, *Heliconia* sp. successfully removed 72% of total nitrogen in landfill leachate due to the underground tissues (root) showed a greater accumulation capacity. However, there are few attempts of using the *Heliconia* sp. in removing of nutrients such as ammoniacal nitrogen, nitrate and nitrite from the lake water. Therefore, this study was conducted to investigate the efficiency of using *Heliconia* sp. in removal of ammoniacal nitrogen from lake water near palm oil plantation.

1.2 Problem statement

The widely used chemical fertilizers in palm oil plantations has been reported to release the excessive nutrients (N and P) into the nearby water body causing the concentration level to exceed the standard regulated level (0.1 mg/L and 0.2 mg/L). This exceeding level is normally associated with the eutrophication phenomenon. The phenomenon occurs due to the excess of nutrients, which are nitrogen and phosphorus that will stimulate the algae growth. Over 20 years ago, the estimated fertilizer used for palm oil industries (estate only) in Malaysia is about 280,133 and 315,148 tones for nitrogen and phosphorus, respectively (FAO, 2004). Nowadays, there are various.

types of conventional nitrogen removal technologies, which can be divided into physiochemical and biological means. Each method relies on different operating principles and conditions. However, these technologies are costly in terms of operation, maintenance and production because they require chemical reagents or complementary facilities (Mishra & Maiti, 2017).

ABS technology has the ability to remove nutrients from lake water. Previous researchers such as Marques *et al.* (2017) and Boxman *et al.* (2018) suggested using an environmental friendly technology such as aquaponic system which is used as an efficient nutrients remover. Aquaponic system can act as a fish culture, plant cultivation and removal of ammoniacal nitrogen in water circulating system (aquaponic). Many researchers have studied the use of ABS to treat fish wastewater (Marques *et al.*, 2017) and marine fish wastewater treatment (Boxman *et al.*, 2018). However, the utilization of aquaponic system as a method to improve water quality in lake has not yet been well investigated. Therefore, the green technology of aquaponic system might produce effective system for ammoniacal nitrogen removal which provide a more efficient treatment of pollutant in lake water, and this emphasize the novelty of the current work. Aquaponic system used *Heliconia* sp. as a plant to uptake nutrient to clean the water. This method also used tilapia (*Oreochromis niloticus*) as a source of ammoniacal nitrogen to replace ammoniacal nitrogen from fertilizer in palm oil plantation. However, to the best of author's knowledge, not well documented research has been reported on the utilization of *Heliconia* sp. in removing ammoniacal nitrogen which was affected by photoperiod and temperature. Therefore, the effectiveness of ammoniacal nitrogen removal by ABS in lake water need to be investigated as it has potential to be an alternative method for photoperiod and temperature prepared by previous methods. Thus, this study aims to identify the characteristics of lake water to determine the removal efficiency of nutrients from lake water near palm oil plantation through ABS, and to optimize the different environmental effects of *Heliconia* sp. in terms of nutrient uptakes and potential of commercial value.

1.3 Objectives and research questions of study

The main aim of the current work is to investigate the efficiency of aquaponic biofilter for ammoniacal nitrogen removal using *Heliconia* sp. Plant. The specific objectives are as follows:

i. To characterize the pollutants in *Tasik Teknologi* water.
   a) What are the parameters and the mean value for concentration of ammoniacal nitrogen available in the lakes?
ii. To determine the best operating parameters and efficiency of ABS for ammoniacal nitrogen removal.
   a) What is the suitable temperature and photoperiod for Aquaponics Biofilter System?
   b) How the most suitable operating condition for Aquaponics Biofilter System that will give the most effective ammoniacal nitrogen removal?
iii. To analyze the nutrient composition on *Heliconia* sp. (Ornamental plant) after phytoremediation.
   a) How is the value of ammoniacal nitrogen, nitrate and nitrite in root and leaves of the *Heliconia* sp.?

1.4 Scope of study

The present study focused on the removing of ammoniacal nitrogen from the lake which is located in Universiti Tun Hussein Onn Malaysia (UTHM) that surrounds the area of palm oil plantation. Lake water samples were obtained from the Faculty of Civil and Environmental Engineering Lake, *Tasik Teknologi* (1.8586^{o} N, 103.0856^{o} E) from 8.00 to 10.00 a.m. The samples of lake water were analyzed for biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solid (TSS), dissolved oxygen (DO) and ammoniacal nitrogen (AN). The aquaponic biofilter system was designed in a greenhouse scale using plant, *Heliconia* sp. and fish (tilapia, *Oreochromis niloticus*). The plants, of average 30 cm height and a tilapia with approximately 100 grams weight were

selected. The ABS was run for 10 days continuously. The best operating parameters (temperature and photoperiod) for aquaponic as biofilter system were determined based on the effectiveness of ammoniacal nitrogen removal.

1.4 Hypotheses of the study

Several hypotheses can be derived through observation on an operation using Aquaponic Biofilter System (ABS) reactor as follows:

a) If the runoff fertilizers (eutrophication) into the lake water that came from the palm oil plantation are high, then the lake water will be rich in nutrient contents such as nitrogen (ammoniacal nitrogen) and phosphorus.
b) If the relationship between different environmental culture conditions of *Heliconia* sp. and specific growth rates exist, then the growth of *Heliconia* sp. will be different in each environmental culture condition.
c) If the relationship between environmental factors such as temperature and photoperiod and specific growth of *Heliconia* sp. exist, then different factors will affect the growth rates and efficiency of ABS on nutrients removal.
d) If the different environmental culture conditions of *Heliconia* sp. influence the phytoremediation of pollutants from lake water, then different culture conditions will result in different ABS efficiencies.
e) If the different temperature and photoperiod influence the uptake of pollutant (ammoniacal nitrogen, nitrate and nitrite) in leaves, stems and roots of *Heliconia* sp., then there are one suitable temperature and photoperiod that contains high concentration ammoniacal nitrogen, nitrate and nitrite in leaves, stems and roots.

1.6 Significance of study

The presence of ammoniacal nitrogen in water can pose both threat and benefits. The excessive, ammoniacal nitrogen can result in the death of aquatic organisms. However, at its safe level, ammoniacal nitrogen can reduce algae bloom, create clean and non-greenish water, avoid aquatic organism from dead, and remove pungent smell from water.

Optimization of parameters for ABS can determine if *Heliconia* sp. is suitable for aquaponic in Malaysia. The best concentration of carbon dioxide, water temperature and photoperiod for plant to grow well and healthy can also obtained from the optimization study. Furthermore, this research has identified the performance of *Heliconia* sp. as an ammoniacal nitrogen removal in the investigated lake.

The application of ABS can offer many benefits too. Its application in the investigated lake can help to reduce the level of excessive ammoniacal nitrogen that is coming from palm oil plantation. ABS can also compete with other useless plant like weed and water lily from growing.

1.7 Thesis structure

This thesis consists of five chapters. Chapter 1 presents general information on palm oil plantation, ABS and plant potential in removal of nutrients. It is presented in few segments started with the background of study, followed by the problem statement, objectives of study, scope of study, significance of study, and closed with thesis structure.

Chapter 2 contains the review of different topics related to this research. This chapter presents information on the lake water in Malaysia, conventional methods for ammoniacal nitrogen removal, phytoremediation process, selection of fish (*Oreochromis niloticus*), selection of plant (*Heliconia* sp.), plant growth at different factors such as temperature and photoperiod of ABS and the commercial value of product of ABS. Major references are critically reviewed to give a clear view on what is expected from the current effort.

Chapter 3 describes in detail the methodology of this research. The first part describes the sampling process of lake water and the analysis conducted on several

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